STUDY OF THE MACHINABILITY OF HARDENED 100CR6 BEARING STEEL WITH TIN COATED CERAMIC INSERTS

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ABSTRACT

In present work behaviour of TiN coated ceramic tool was investigated considering the effect of workpiece material hardness and cutting parameters (cutting speed, feed rate, depth of cut and cutting time) during turning of hardened 100Cr6 bearing steel. The evolution of surface roughness (*Rz*), cutting forces and tool flank wear has been investigated according to the cutting parameters. Experimental results reveals that the feed rate, workpiece hardness and cutting speed have significant effects in reducing the surface roughness; whereas the higher cutting forces are required for machining harder work material. When tool flank wear (*VBc*) of TiN coated ceramic tool increases, cutting forces increase. The most dominating force component was the thrust force, followed by the tangential cutting force; the axial force was less sensitive to tool flank wear evolution. Finally, tool flank wear rate increase smoothly and the wear mechanism was probably abrasion and adhesion especially in case of harder workpiece.

Mots Clés: *100Cr6 steel, TiN coated ceramic tool, flank wear, cutting forces, surface roughness.*

NOMENCLATURE

Symbols :
Vc cutting speed, m/min
f feed rate, mm/rev
ap depth of cut, mm
t cutting time, min
Rz surface roughness, µm
VBc tool flank wear, mm
Fr thrust force, N
Ft tangential cutting force, N

Greek symbols :
γ negative rake angle, deg
λ inclination angle, deg
α clearance angle, deg
κ_r cutting edge angle, deg

1. INTRODUCTION

High-hardness materials include various hardened alloy steels, tool steels, case-hardened steels, super alloys, nitrided steels, hard-chrome coated steels, and heat-treated powder metallurgical parts. Finishing of hardened steel, (e.g. through hardened 100Cr6 steel for bearing applications, and case hardened steel 16MnCr5 for automotive gears and shafts) using hard turning using super hard cutting tools (PCBN, cubic boron nitride (CBN), Ceramics, and Carbide) was early recognized by the automotive industry as a means of manufacturing of precisely finished transmission components [1].

Hard turning process differs from conventional turning because of the workpiece hardness, the required cutting tool, and the mechanisms involved during chip formation. Whenever machining given parts straightforwardly after they have been hardened, hard turning offers a number of potential advantages over traditional grinding, including lower equipment costs, shorter setup time, fewer process steps, greater part geometry flexibility, and usually there is no need cutting fluid use. If hard turning could be applied to fabricate complex parts, manufacturing costs could be reduced by up to 30 times [2]. It protects the wear substrate, improves the crack resistance and created a thermal barrier [3]. With advent of new kind of tools such as Cubic Boron Nitride (CBN), Polycrystalline Cubic Boron Nitride (PCBN), poly-crystalline diamond (PCD), coated, Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD) and ceramic tools, better surface finish will be accessible without any finishing and complementary operation such as grinding.

Several researchers have made attempts to understand the effect of various machining parameters for the control of the finish hard turning process. Grzesik and Wanat [4] investigated the surface finish generated in hard turning of quenched alloy steel using conventional and wiper ceramic inserts. They concluded that surfaces produced by wiper contained blunt peaks with distinctly smaller slopes resulting in better bearing properties. When using alumina–TiC ceramic tools. Asiltürk and Akkuş [5] reported that the feed rate has the most significant effect on surface roughness. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. Chinchanikar and Choudhury [6] investigated the effect of work materials hardness and cutting parameters on cutting forces, surface roughness and tool life, when turning hardened AISI 4340 steel at two levels of hardness (35 and 45 HRC), using coated tungsten based cemented carbide inserts. Due to inadequate knowledge of the complexity finish hard turning technology, numerous mathematical models have been proposed and extensively developed by a growing numbers of papers for the analysis of the machinability [7–10]. The machining parameters such as cutting speed, feed rate, depth of cut, machining time and workpiece material hardness will highly affect flank wear and cutting forces. When finish hard turning process is applied in metal cutting industry, high dimensional accuracy and better surface finish is urgently demanded. A lot of factors can affect the quality of the surface finish and one of the most affecting is the workpiece material hardness. It is necessary to select the most appropriate machining settings in order to improve cutting efficiency, process at low cost, and produce high-quality products.

The present work lays out experimental results on the TiN coated ceramic flank wear behaviour when dry machining hardened 100Cr6 bearing steel widely used in manufacturing industry. In addition, surface quality, and cutting forces evolution are examined as a function cutting parameters (cutting speed, feed rate depth of cut and cutting time) at three different workpiece hardness levels.

2. MATERIALS AND EXPERIMENTS

In the present investigation, the workpiece material is an 100Cr6 steel bars. This material is being used for the manufacturing of the bearing rings and automotive components. The nominal chemical composition of 100Cr6 steel is shown in Table 1. These bars are nominally of 54 mm diameter and were cut to 400 mm length prior to heat treatment. In order to reach three different hardness levels 46, 52, and 62 HRC, with error ratio of ±1 HRC. The microstructure of the 100Cr6 steel in the as-cast condition and in annealed condition after Etching with Nital 0.3% is shown in Fig.1. In this hypereutectoid steel, the microstructure was almost completely formed by pearlite.

Chemical composition	C	Si	Mn	S	Cr	Mo	P	Cu
Measured values	**1.05**	**0.23**	**0.35**	**0.028**	**1.45**	**0.04**	**0.01**	**0.28**

TABLE 1. Nominal chemical composition of 100Cr6 steel (wt %)

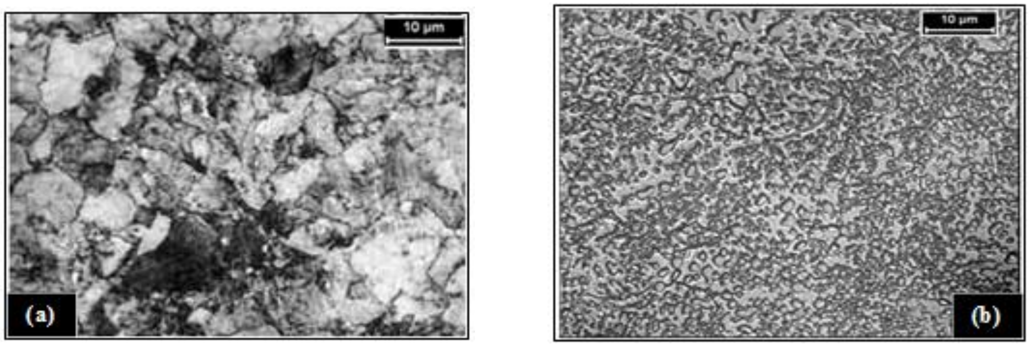

FIGURE1. Microstructure of the 100Cr6 steel: (a) the as-cast condition and (b) in annealed condition after Etching: Nital 0.3%.

Initially, the bars were heat treated at 840°C (austenization temperature) for 1 h and quenched in oil at 80−100°C for 20 min. After that, tempering was carried out for 1 h at the following temperatures: 480°C (46 HRC), 380°C (52 HRC), and 170°C (62 HRC) followed by air cooling. Hardness measurements were carried out using a Hardness Tester Mitutoyo HH-401. The cutting tool used was TiN coated mixed ceramic inserts (Sandvik's Grade CC6050) in accordance with ISO designation of SNGA 120408S01525 is shown in Fig.2. The inserts were clamped onto a tool holder with a designation of PSBNR2525M12. Combination of the insert and the tool holder resulted in negative rake angle γ= -6°, clearance angle α=6°, negative cutting edge inclination angle λ=-6° and cutting edge angle κ_r =75°. The lathe used for machining operations is TOS TRENCIN; model SN40C, spindle power 6.6 KW. The cutting forces in three directions were recorded using a standard quartz dynamometer (Kistler 9257B) allowing measurements from −5 to 5 KN.

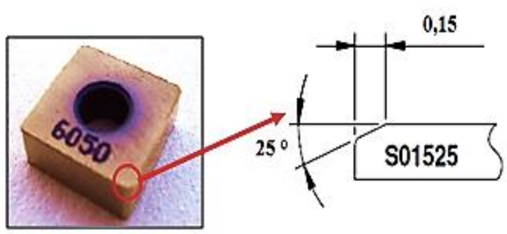

FIGURE 2. Coated mixed ceramic insert.

The measurement chain also included a charge amplifier (Kistler 5019B130), data acquisition hardware (A/D 2855A3) and graphical programming environment (DYNOWARE 2825A1–1) for data analysis and visualization.The whole measurement chain has been statically and dynamically calibrated. The static calibration of the dynamometer was made in each force direction. When performing the cutting force analysis, average value of the cutting force peaks in the steady state of cutting were selected. The sampling frequency of data was set at 5000 Hz. The tool wear has been measured using an optical microscope (HUND W-AD) equipped with a CCD camera. Three components of the resultant force are shown schematically in Fig.3.
The measurements of surface roughness (*Rz*) for each cutting condition were obtained from a Surftest 201 Mitutoyo roughnessmeter. The length examined is 24 mm with a basic span of 3 mm.

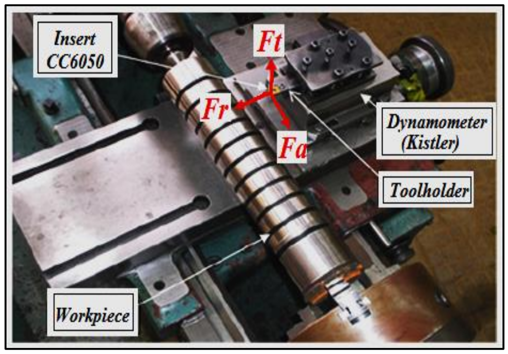

FIGURE 3. Experimental configuration.

The measurements were repeated at three equally spaced locations around the circumference of the workpieces and the result is an average of these values for a given machining pass.

3. RESULTS AND DISCUSSION

In the present investigation, after each cutting experiment carried out according to the experiment parameters, the *Rz* roughness values were measured over the machined surfaces. The graphs showing the correlations between the measured values and the machining parameters are given in Fig.4 (a) and (b). The curves are placed based on workpiece hardness on the graphics.

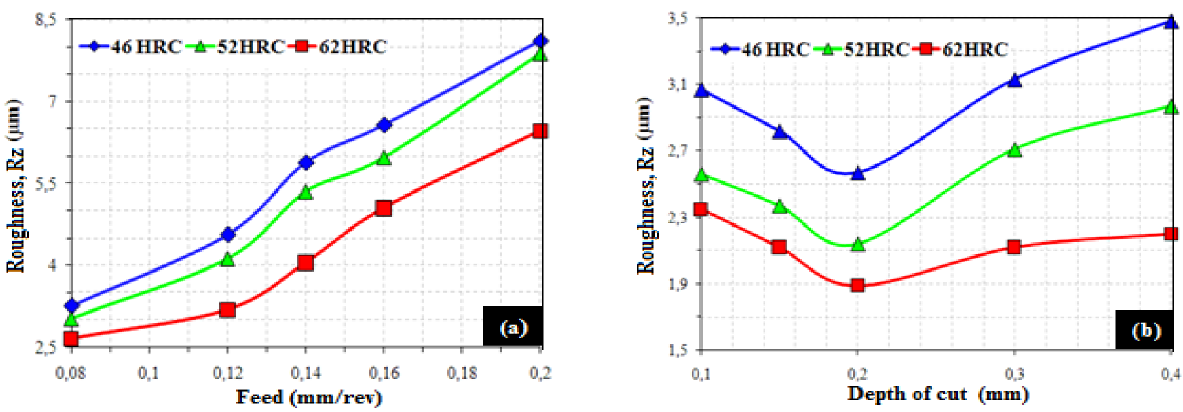

FIGURE 4. Roughness (*Rz*) evolution as a function of cutting conditions for: (a) *Vc*=120m/min; *ap*=0.2mm. (b) *Vc*=120m/min ; *f*=0.08mm/rev

It can be seen that the roughness (*Rz*) value of the machined surface increases sharply with the increase in feed (Fig.4(a)). This is because increase in feed leads to produce feed marks on the turned surface resulting in the increase in the roughness value. In practice the consequences of the influence of *f* on the surface roughness could be summarized as follows: when *f* increases from 0.08 to 0.2 mm/rev and workpiece surface hardness from 46 to 62 HRC, surface roughness increases by factors of 3 and 3.5 times, respectively. Nevertheless, despite the increase of feed the values of surface roughness are still acceptable and even can be compared to those obtained by grinding process. Fig. 4 (b) show that when increasing *ap* from 0.2 mm surface roughness increases, On the other hand, it can be seen that the increase in depth of cut leads to increase in radial forces more prominently resulting in more lateral vibrations of tool and hence, increase in roughness value of the turned surface.

Fig.5 (a) and (b) shows the variation of cutting forces with cutting time and workpiece surface hardness. It is seen that the cutting forces increased as a function of in workpiece hardness, and hence as a function of cutting time. This is due to wear evolution on the rake and clearance surfaces of the tool. As a consequence the workpiece-tool contact surface increased together with the friction forces, generating higher cutting forces. The thrust force is about twice that of tangential cutting force in dry hard turning in terms of trial conditions and it is most sensitive to the workpiece hardness variation.

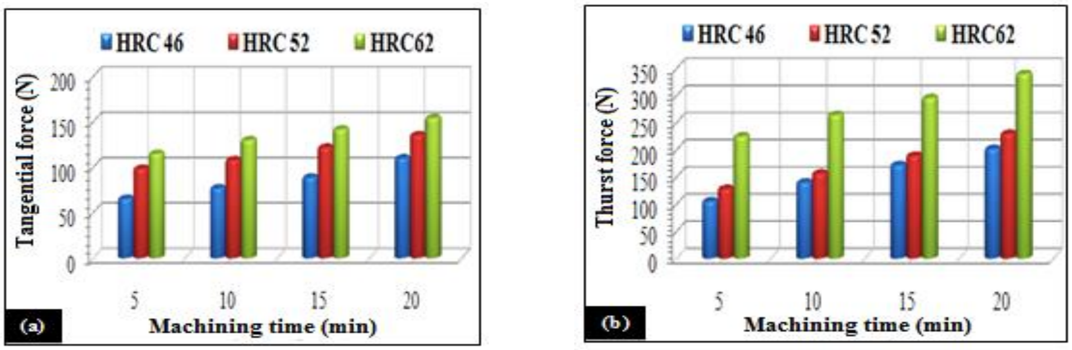

FIGURE 5. Cutting forces evolution as a function of cutting conditions
for: *Vc*=170 m/min, *f* =0.08mm/rev and *ap*=0.2mm.

Fig. 6 show the influence on cutting time no average flank wear (*VBc*) after dry hard turning for 5, 10, 15 and 20 min under the following cutting conditions: *V*c = 170 m/min, *f* = 0.2 mm/rev and *ap* = 2 mm. The measurement of *VBc* was not cumulative, i.e., a fresh cutting edge was used for each cutting time. It can be noticed that when flank wear increased smoothly as cutting time elapsed. In spite of the difference in the properties of the workpiece materials hardness tested, the higher workpiece hardness value was responsible for the accelerated wear rate. The flank wear in the TiN coated ceramic cutting tools is a mechanically activated wear usually by the abrasive action of the hard workpiece material with the ceramic cutting tools. It occurs on the relief face of the cutting tool and is generally attributed to the rubbing of the tool along the machined surface and high temperatures causing abrasive and/or adhesive wear, thus affecting tool materials properties as well as workpiece surface. The flank wear morphology were shown in Fig. 7 when dry turning hardened steel by TiN coated ceramic tool.

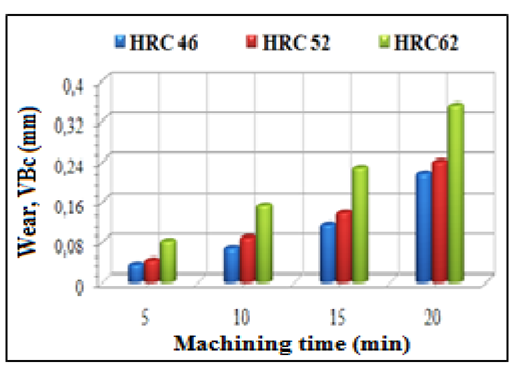

FIGURE 6. Tool flank wear evolution as a function as a function machining time and workpiece hardness.

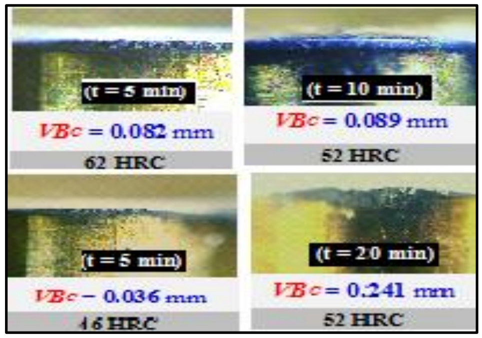

FIGURE 7. Tool flank wear morphology as a function machining time and workpiece hardness.

4. CONCLUSIONS

The main results that can be deduced from the present investigation concerning the machinability of hardened 100Cr6 steel using TiN coated ceramic tools are summarized here:

. The surface roughness increases with the increase of feed rate and almost decreases with the increase of workpiece hardness.

. When feed rate increases from 0.08 to 0.2 mm/rev and workpiece surface hardness from 46 to 62 HRC, surface roughness increases by factors of 3 and 3.5 times, respectively.

. Flank wear phenomenon is dominantly by abrasion process. It is generated through scratches behaviour on the tool flank surface. Abrasion wear is due to the removal of TiN coated ceramic tools particles by hard small grains of the material being machined. The presence of Fe and Cr on the tool rake face implies that adhesive wear can also participate to the wear mechanisms of TiN coated ceramic tools particles.

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